Conjugated organic materials for active layers in transistors: Assessement of the electrical stability properties

H. L. Gomes[1], P. Stallinga[1], and D. M. de Leeuw[2]

[1] Center of Electronics Optoelectronics and Telecommunications, Faro, Algarve, Portugal

[2] Philips Research, Eindhoven, The Netherlands

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Outline

Motivation "Plastic electronics"

CEOT, OptoEl, Univ. do Algarve

"Stress" in FETs
(Bias-induced threshold voltage shift)

Temperature and bias dependence

Conclusions

Electronics of the past

Electronics of the Future
“Ambient intelligence”

Example: Paper Electronics

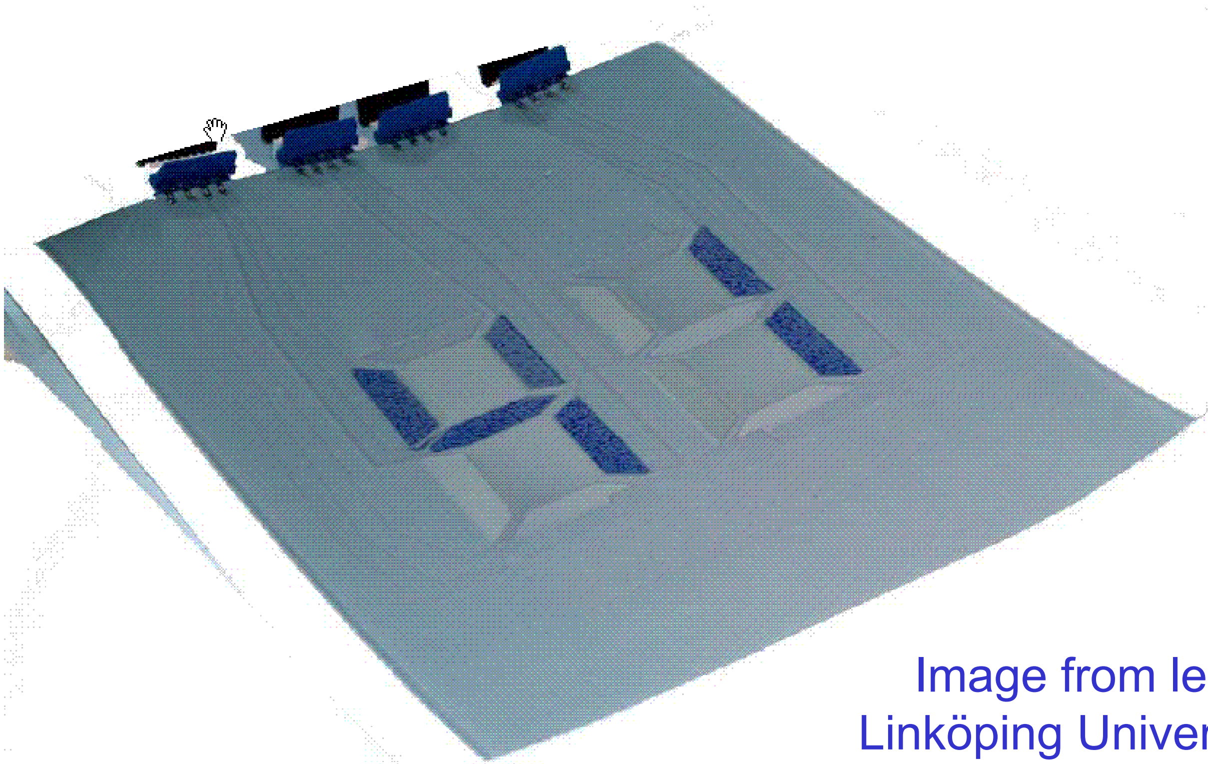
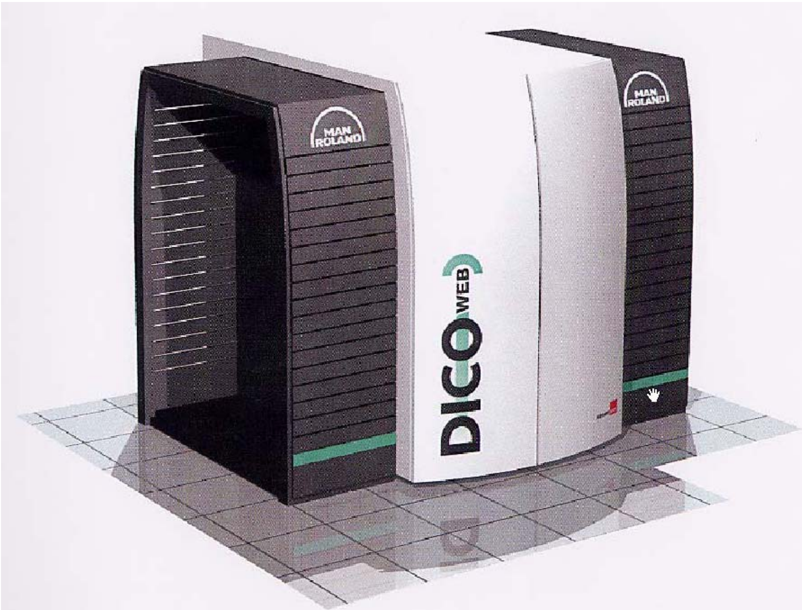


Image from lecture of Magnus Berggren, Linköping University at TPE04 (Rudolstadt)

Example: Printable Electronics



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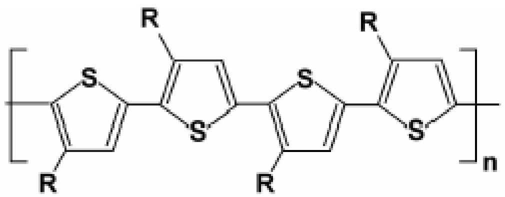
WE ARE PRINT.™

Using existing technologies (offset, gravure and flexo printing) to produce electronic circuits

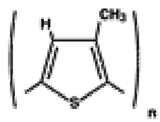
… only organic electronics!

Reinhard Baumann,
MAN Roland Druckmaschinen AG, Germany

Organic semiconductors at CEOT

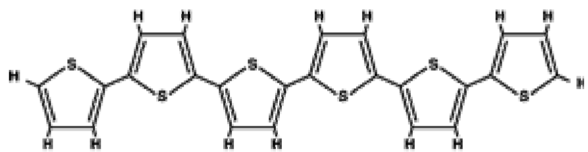


regio-regular poly(thiophene)



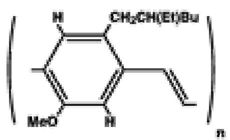
PMeT

Poly(methyl-thiophene)



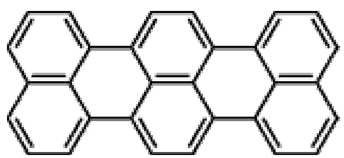
αT6

Sexi-thiophene (T6)

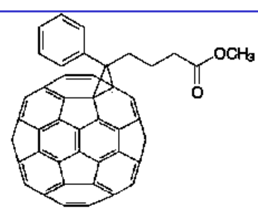


MEH-PPV

Poly(phenylene-vinylene)



Terrylene



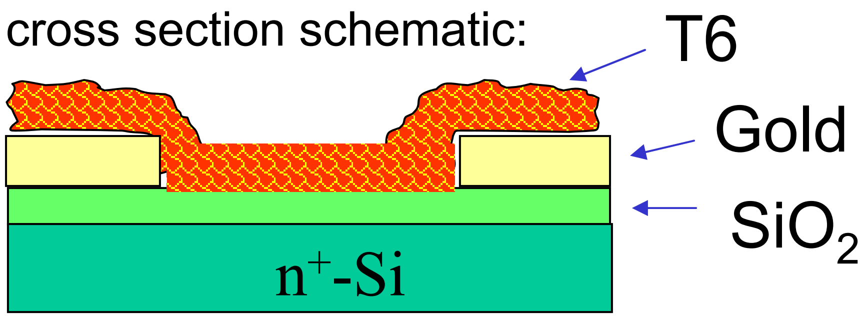
[6,6]-phenly-C61-Butyric acid methyl ester (PCBM)

Example of a Field Effect Transistor

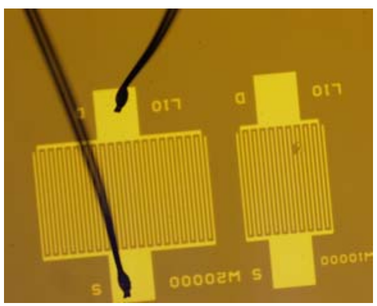
Vacuum sublimed organic thin film (α-sexithiophene)

Thickness: 4-8 nm

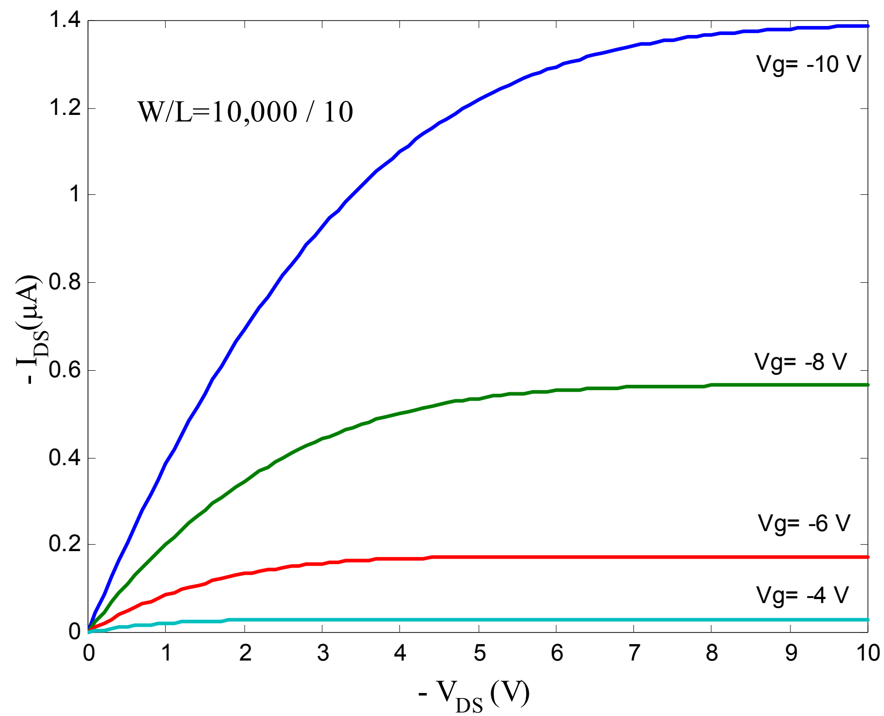
cross section schematic:



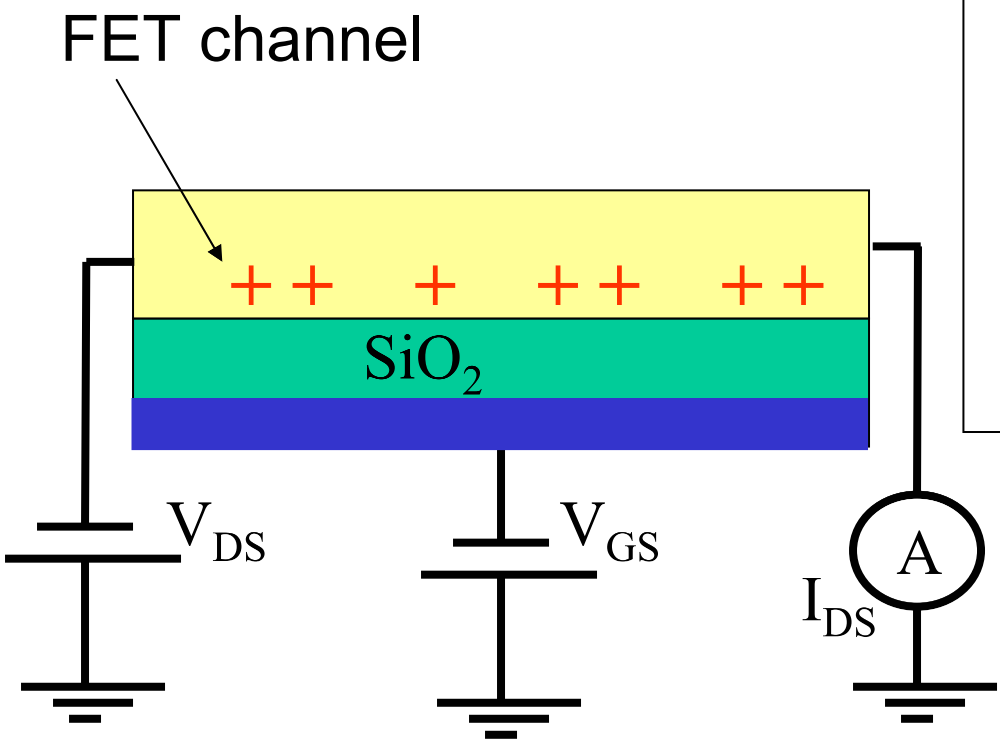
top view:

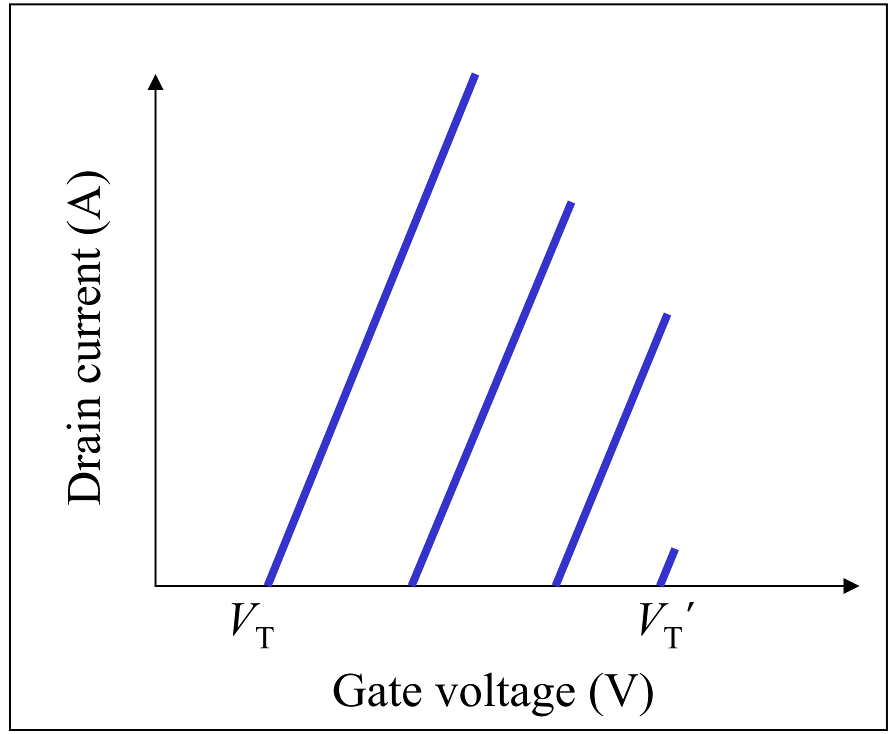


$\mu \approx 10^{-2}$ cm^2/Vs



Bias-induced threshold voltage shift





Stress effects and other effects

Stress caused by **traps**.
Traps manifest themselves also in

non-linear transfer curves ($I_{ds} \approx V_g^{1+\gamma}$) A

field-dependent mobility (V_g and V_{ds}) A

Meyer-Neldel observation (thermal activation of current) B

Non-exponentially decaying currents (Kohlrausch, 19th century) A

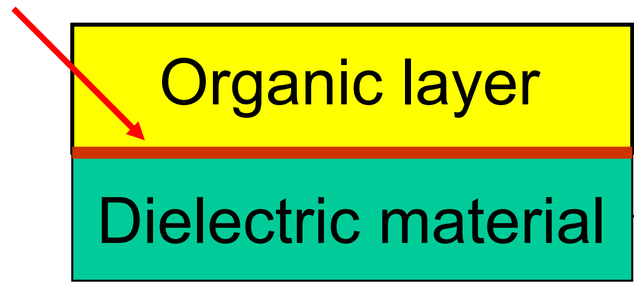
Very similar to amorphous silicon C, D

A: Stallinga *et al*., J.Appl.Phys. **96**, 52577 (2004)
B: Stallinga and Gomes, Organic Electronics 2005
C: Powell, IEEE Trans.El.Dev. **36,** 2753 (1989)
D: Shur and Hack, J.Appl.Phys. **55**, 3831(1984)

Stress effects and the dielectric properties

Different surface

chemical treatments



Thermally grown SiO_2

PECVD SiO_2

Plastic insulator

Stress occurs, even when different dielectric and different surface treatments are used!

Materials suffering from stress effects

Polythienyle vinylene (PTV) A. R. Brown *et al*. (1997)

Pentace M. Matters *et al*. (1997)

α-sexithiophene W. A. Schoonveld *et al*. (1999)

Poly(3-dodecylthiophene) S. Scheinert *et al*. (2002)

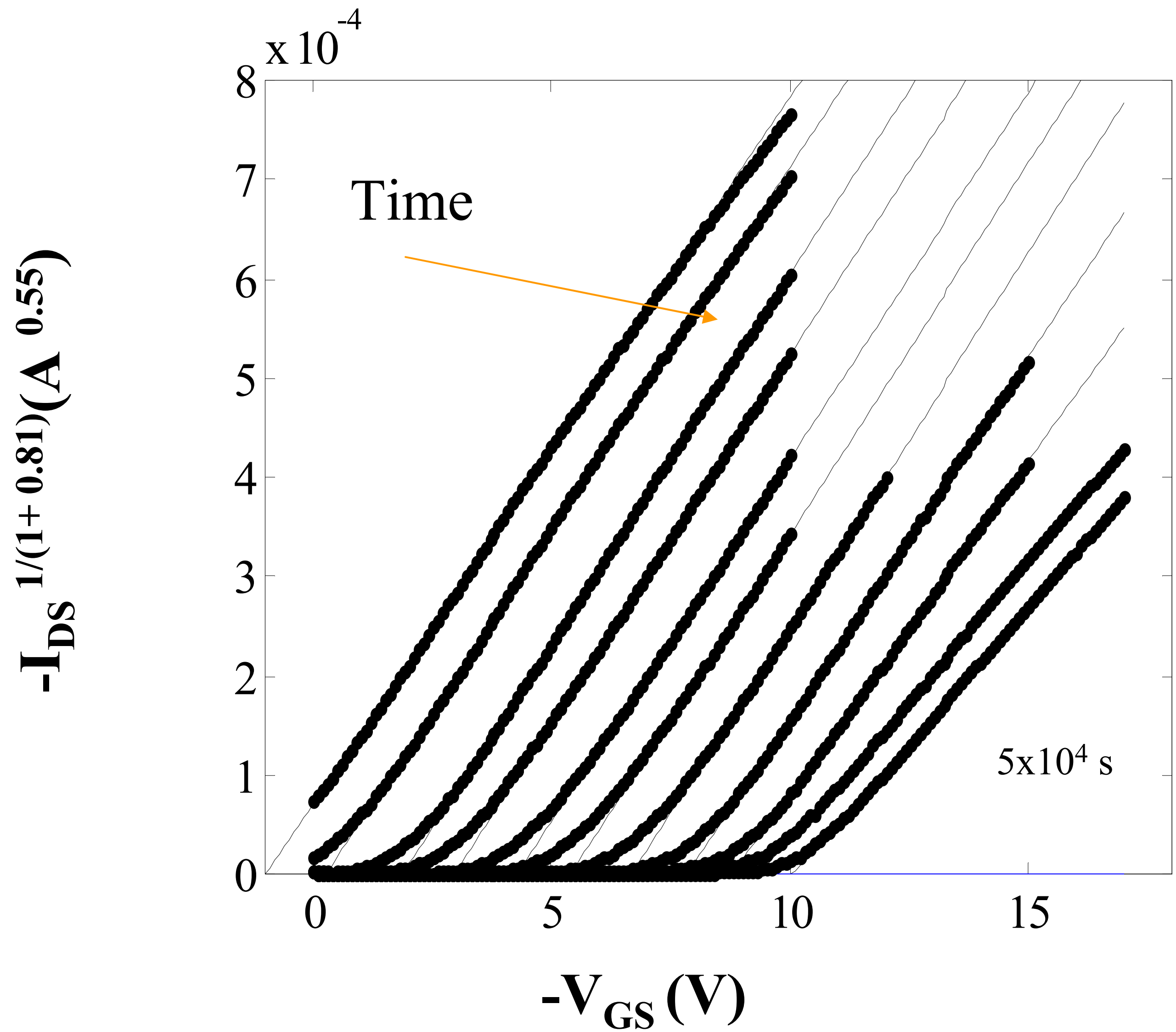
Regioregular-polythiophene.

Poly-9,9´dioctyl-fluorene-co-bithiophene

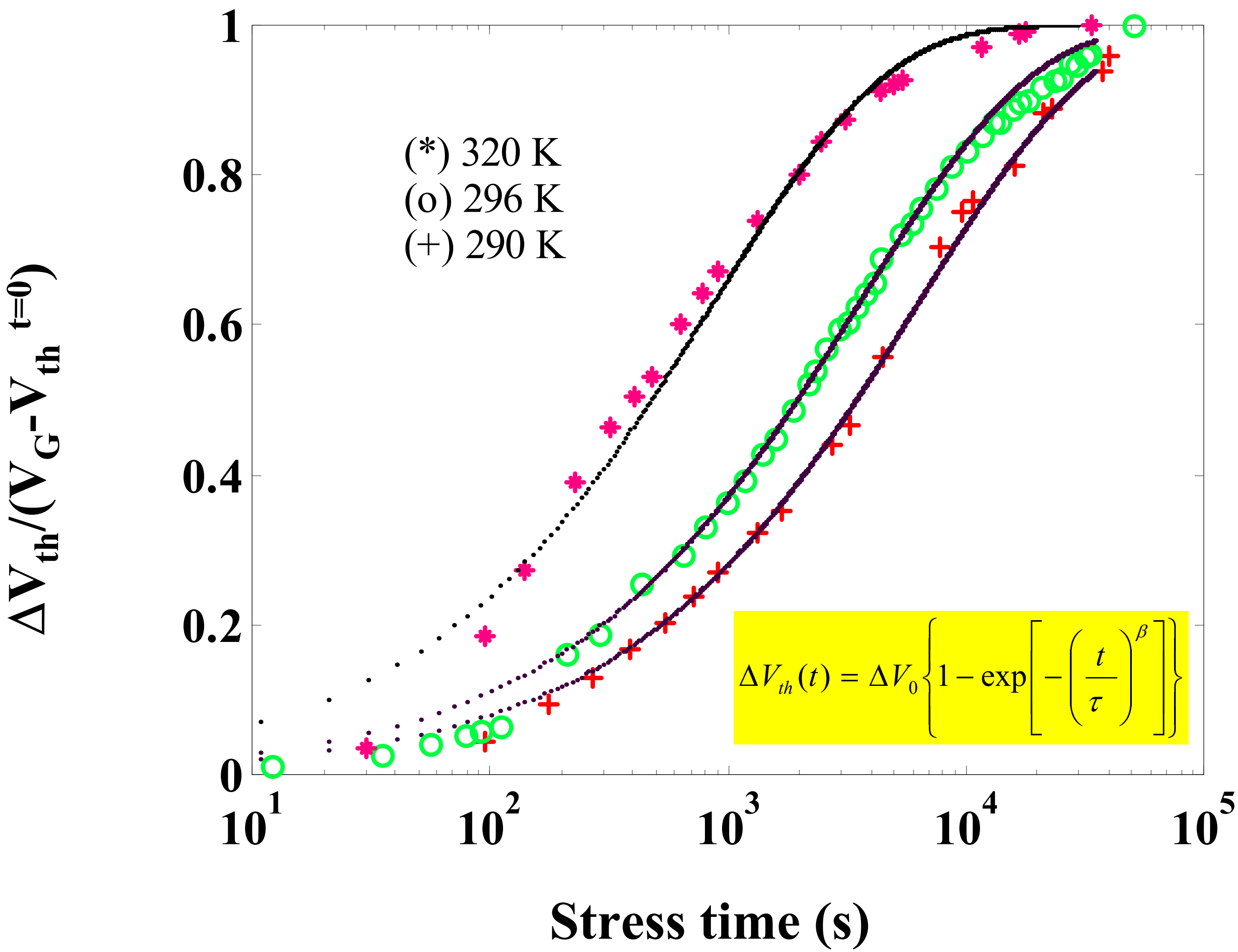
A. Salleo and
R. A. Jianfeng Yuan (2004)

Fluorinated copper phthalocyanime Street (2003)

Electrical characteristics



“Stretched exponential” behavior



What is the nature of the traps?

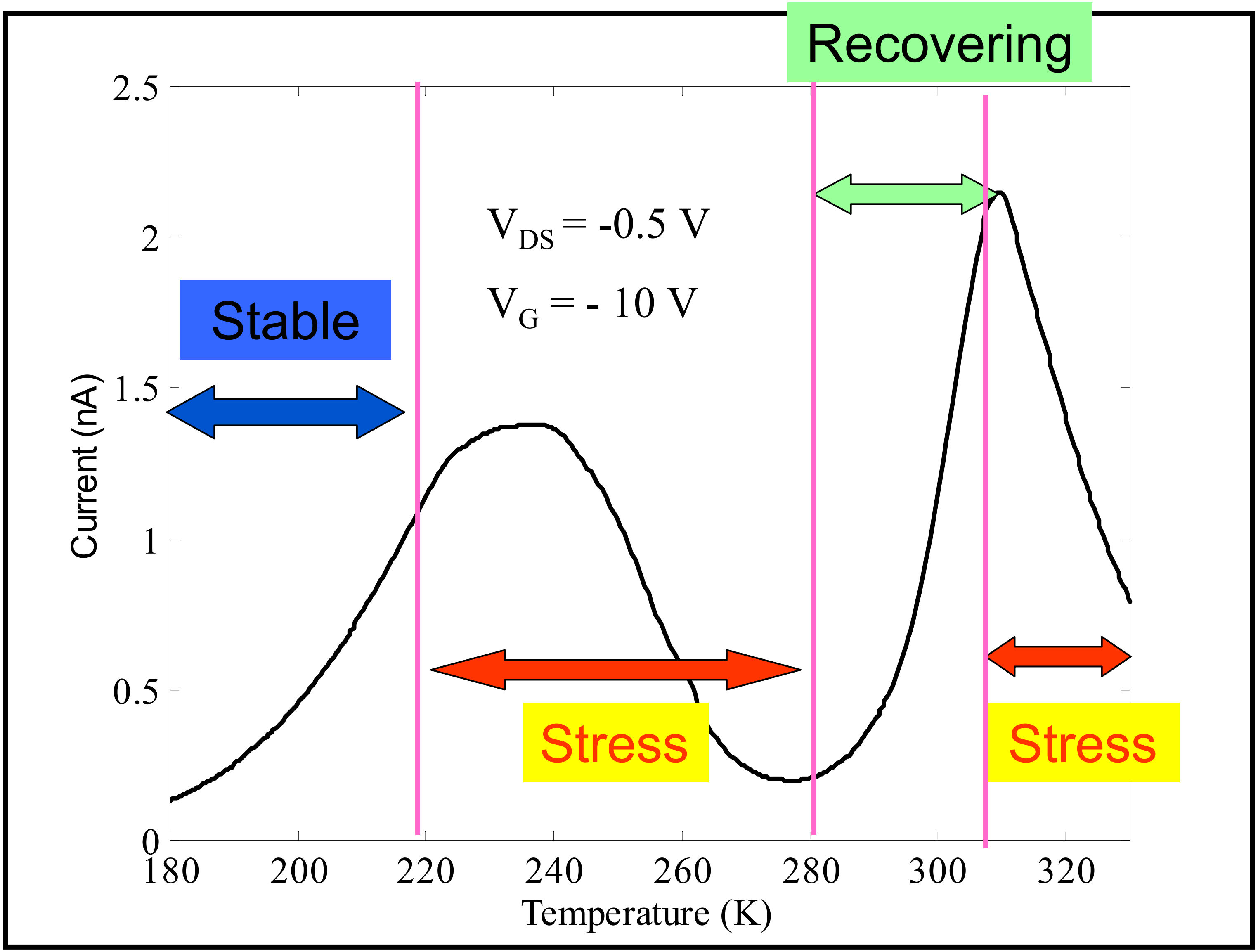
Existing traps?

Created by the electric field?

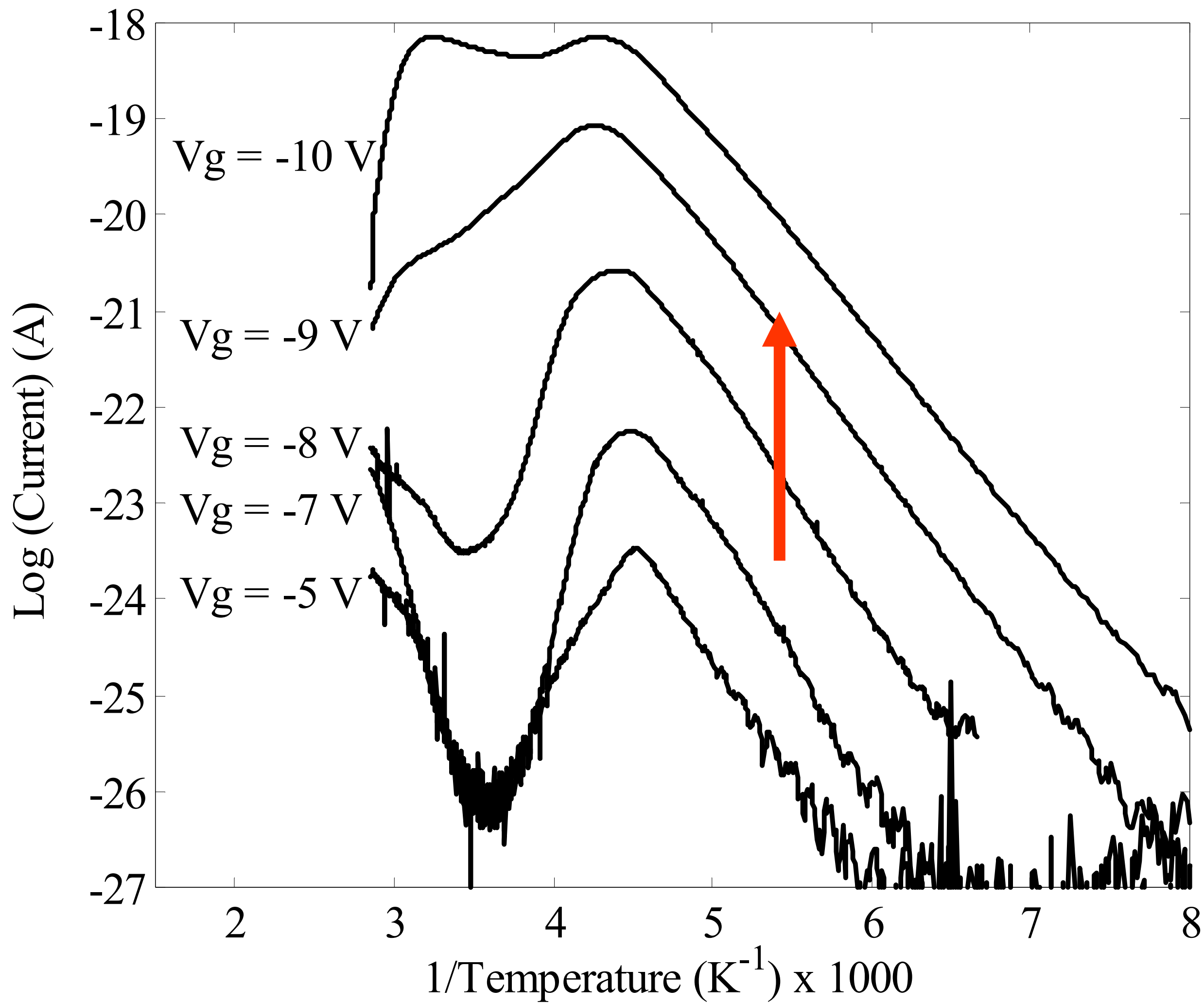
Created by temperature (phase transition)?

Efficiency of trapping seems to be 100%
(any free charge is eventually trapped)

Temperature dependent current



Gate bias dependence



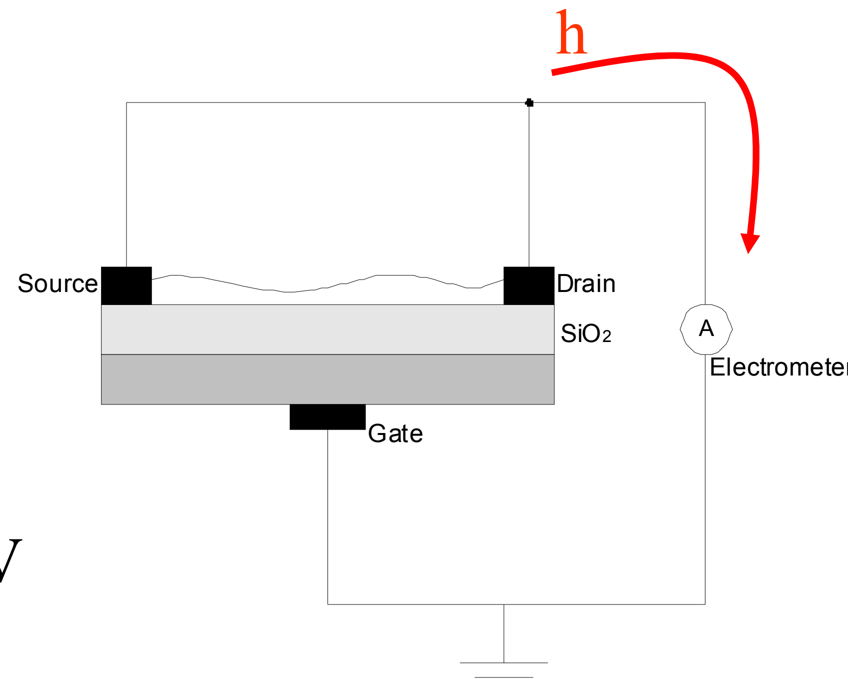
Detrapping experiments

Cool down to 180 K with

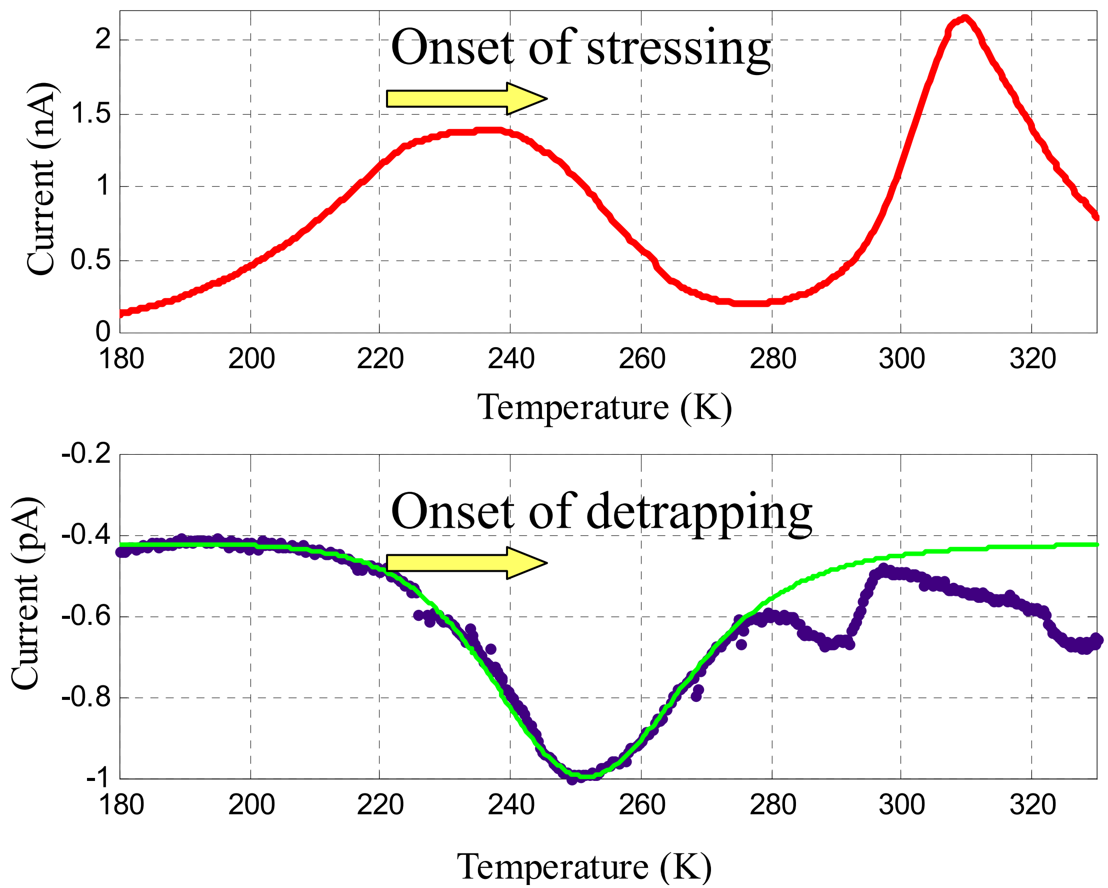
$V_g = -10$ V (fully stressed)

Warm up to 340 K with $V_{DS} = 0$ V

while measuring the hole-detrapping current.



Detrapping current TSC



Device current

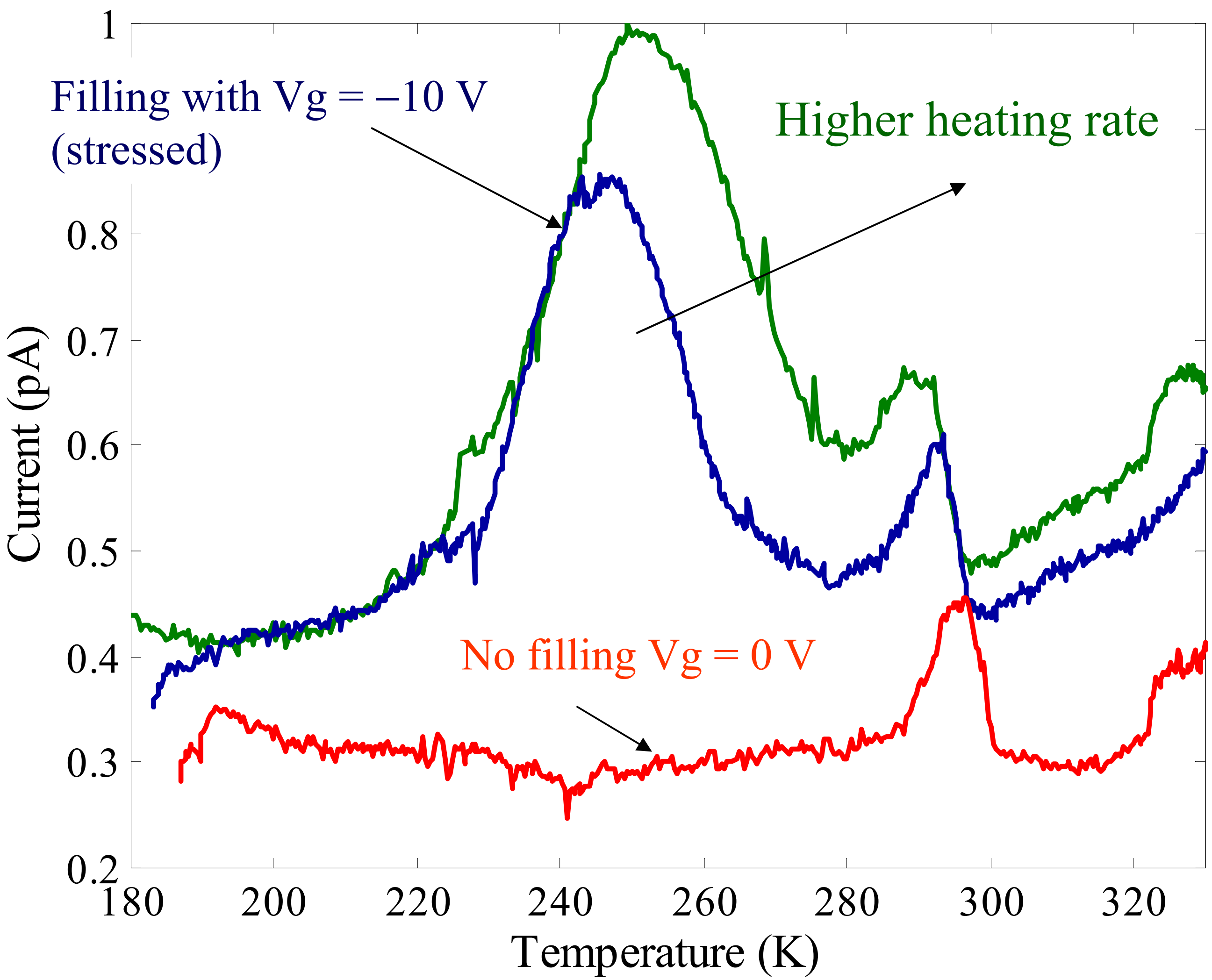
Detrapping current

$$I = \frac{A\exp(-\psi)}{\left[1 + B\exp(-\psi)\psi^{-2}\right]^2}$$

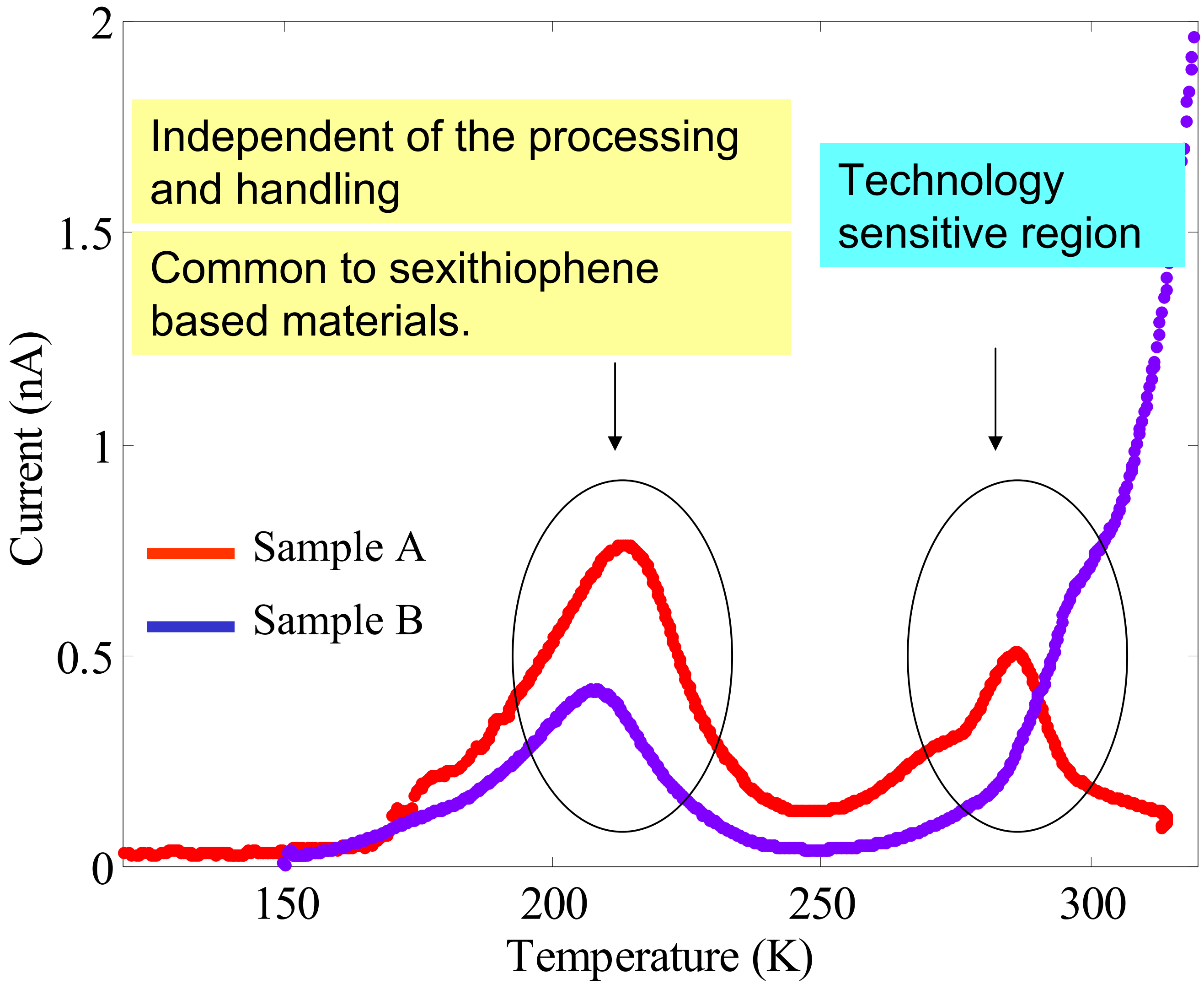
$$\psi = E_A/kT.$$

$$E_A = 0.51\ \text{eV}$$

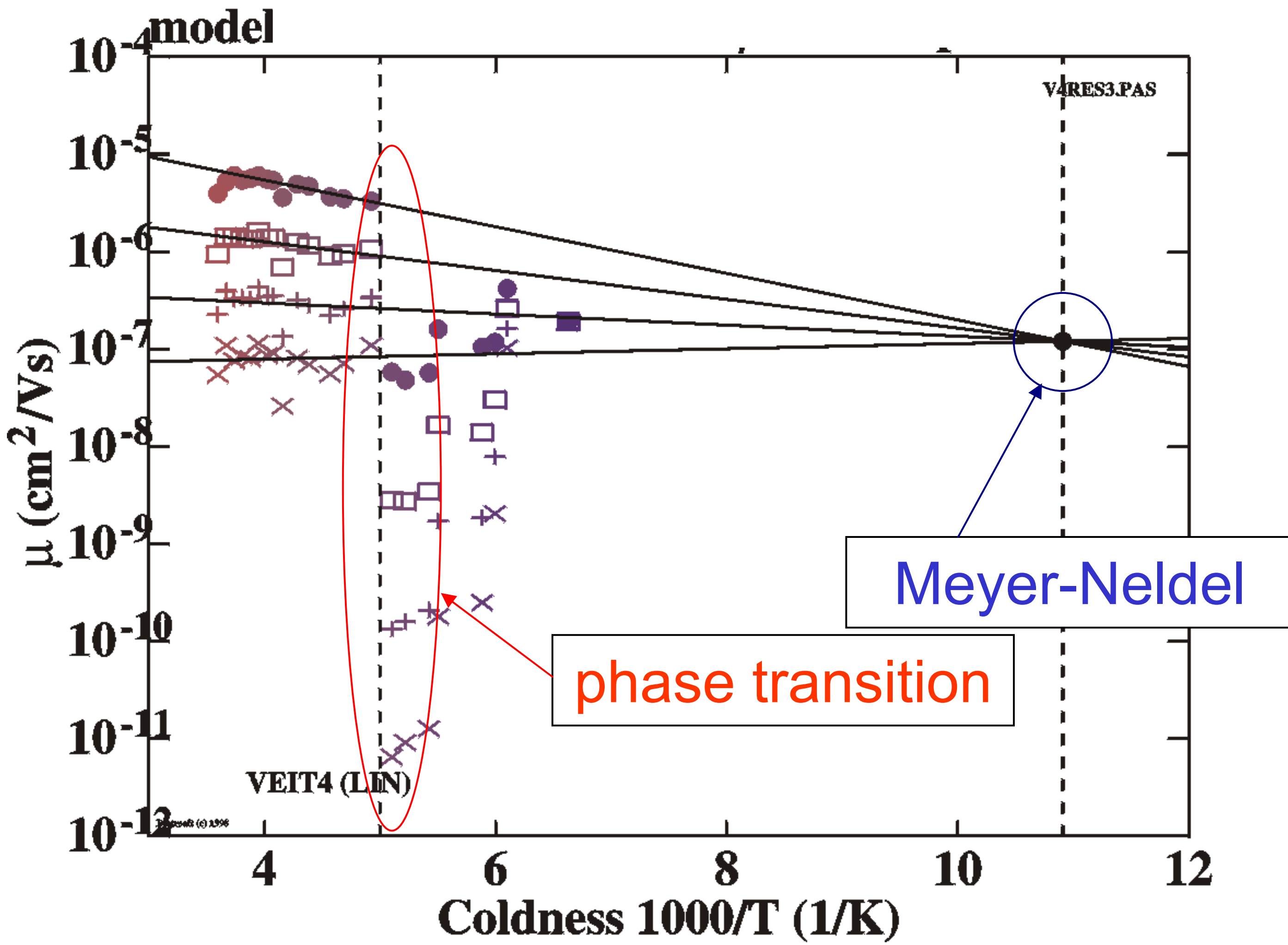
Detrapping current



Sample dependence



Phase transition in nano-FET?



Vg =

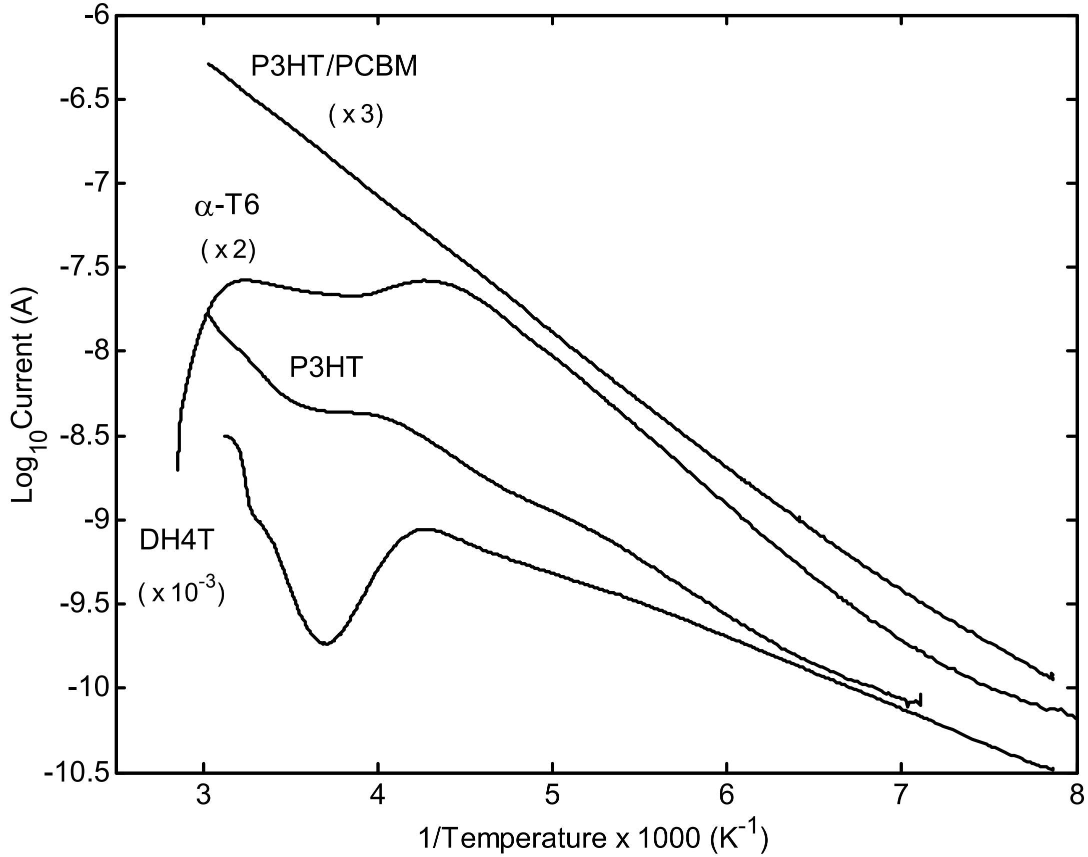
●: -12 V

□: -10 V

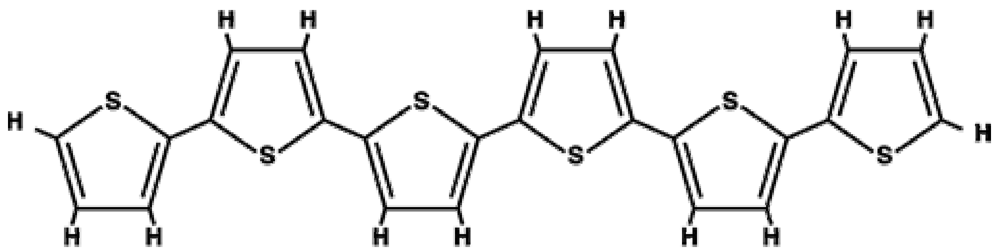
+: -8 V

x: -6 V

Different materials

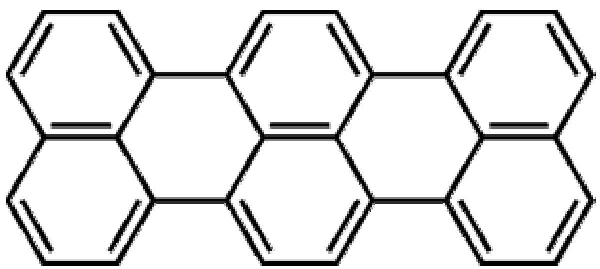


Different materials



αT6

αT6 strong stress at 220 K



Terrylene: No stress at 220 K

Conclusions

A “phase transition” occurs at T = 220 K, inducing **new** traps in the sample.

These traps states can be filled with holes and they are responsible for the stress effects.

At RT a new process sets in, causing further trapping. This process strongly depends on the handling and production conditions.

Stress is reversible (pulsed mode)

Different materials suffer from stress differently (rigid molecules are less prone to stress)

Acknowledgements

Dago de Leeuw
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(CNR, Bologna, Itália)

MONA-LISA

Development of Novel Conjugated **MO**lecular **NA**nostructures by **LI**thography and their Transport **S**caling **A**spects.

European Comunity project

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